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Analysis and interpretation of long-temporal-trends in temperatures amounts and olive reproductive features by Seasonal-Trend Decomposition Procedure

Fátima Aguilera[1]*, Fabio Orlandi[1], Luis Ruiz-Valenzuela[2], Monji Msallem[3], Marco Fornaciari[1]

[1]Department of Civil and Environmental Engineering, University of Perugia, Borgo XX Giugno 74, 06121 Perugia, Italy

[2]Department of Animal Biology, Plant Biology and Ecology, University of Jaén, Agrifood Campus of International Excellence (CeiA3), Campus of the Lagunillas s/n, 23071 Jaén, Spain

[3]Institut de l'Olivier, BP 208, 1082 Tunis, Tunisia

***Corresponding author**: Fátima Aguilera

Department of Civil and Environmental Engineering

University of Perugia,

Borgo XX Giugno 74, 06121 Perugia, Italy.

Tel: +39-075-5856411

Fax: +39-075-5856425

e-mail: faguiler@ujaen.es

Abstract

The aim of the present study was the analysis and interpretation of long-temporal-trends in temperatures amounts and olive reproductive features including full flowering dates and daily pollen concentrations in several Mediterranean areas. The study was performed using 19-year database (1993-2011) of pollen and temperature records obtained for Perugia (Italy), Jaen (Spain) and Zarzis (Tunisia). The analysis of long-term trends in both the temperature amount and the olive reproductive cycle was performed using two approaches. On the one hand, a Seasonal-Trend Decomposition procedure based on Loess (STL) technique was performed. STL is a filtering procedure for decomposing a seasonal time series into three components: trend, seasonal, and remainder. On the second hand, the trend components were analyzed using the Mann-Kendall test. The use of the STL has result a good approach to study long-term meteorological and phenological trends. Removing both the seasonal and the remainder components the real rising trends over time can be interpreted. In general, a significant and clear increasing trend in the spring temperature amount was detected. Decreasing trends in the full flowering dates of the olive trees located in Perugia and Zarzis sites were evident. Moreover, the olive pollen emissions are decreasing, phenomenon more evident in the highest and lowest latitudinal study sites. The findings herein imply that increasing temperatures result in both olive tree flowering advance and lower airborne pollen emission. In consequence, lower atmospheric pollen levels would reduce the human exposure to olive pollen in the Mediterranean area. The pattern is clearer in the highest and lowest latitudes where the olive cultivation is present, but not in the intermediate latitudes such as the Spanish area, where more research should be needed.

Keywords: flowering, Mediterranean region, phenology, pollen emission, temperature, trend

1. Introduction

Plant phenology is sensitive to the weather, mainly to the temperature and rainfall patterns (Aguilera et al. 2013; Orlandi et al. 2014; Osborne et al. 2000). Of all the biological cycle, flowering is one of the more critical phases for every fructiferous plant (Barranco et al. 2008). In the olive tree (*Olea europaea* L.), weather conditions prior to flowering such as low temperatures and high precipitation promote the formation of flowers and contribute positively to increased pollen production (Aguilera and Ruiz-

Valenzuela 2012a). In addition, cumulative rainfall during the flowering period can influence its length and also the pollen release (Galán et al. 2008; Oteros et al. 2012; Recio et al. 1996).

Numerous studies have demonstrated that reproductive phenology is an important and useful indicator of the impact of climate change (Menzel and Sparks 2006; Moriondo et al. 2013). Olive flowering period is considered a good bio-indicator of global warming mainly through its dependence on temperature and through its geographical distribution over one of the most high-risk warming areas on the Earth (Moriondo et al. 2008; Orlandi et al. 2014; Osborne et al. 2000). However, the availability of long-time series of data that can be used to detect significant phenological changes is not so frequent. For this reason, among the different types of phenological datasets that can be distinguished, the measurements of pollen emissions in the atmosphere are generally the most used (Chuine et al. 1999). Many studies have thus used aeropalynological information to analyze the flowering phases in anemophilous species, with airborne pollen data widely used as a well-proven tool for the indirect evaluation of the flowering period (Aguilera and Ruiz-Valenzuela 2009; Orlandi et al. 2010).

Nowadays, the olive tree is one of the most widespread arboreal cultivated species across the Mediterranean basin. This species is adapted to the climatic and territorial conditions of this region, being the dominant crop throughout its rural area (Barranco et al. 2008; Romero 1998). Therefore, olive groves constitute a fundamental part of the Mediterranean environment, culture and economy, as the olive fruit and oil are among the oldest and most important products (Loumou and Giourga 2003).

Over 750 million olive trees are cultivated worldwide, 95% of which are in the Mediterranean basin (International Olive Council, IOC, 2013). Spain is the largest olive-oil-producing country, followed by Italy, Greece and Tunisia. Together, these four countries produce 80% of the total world olive-oil production (IOC 2013). One of the consequences is that the olive pollen type has become the most abundant within the pollen spectrum, due both the notable increase in its cultivation area and to the intense flowering of the trees, which release large amounts of pollen grains into the atmosphere during spring (Aguilera and Ruiz-Valenzuela 2012a; García-Mozo et al. 2008). The pollen emitted by olive trees is considered as one of the main causes of respiratory allergic disease in the Mediterranean region (D'Amato et al. 2007). In countries of olive cultivation vocation as Spain, Italy, Greece, Tunisia or Turkey, olive pollen is the most important cause of pollinosis, provoking seasonal allergic rhinitis and bronchial asthma among the population. Warming trends and spatial variability of the rainfall regimes are both expected in the future (Giorgi and Lionello 2008; Vergni and Todisco 2011), and could be reasonably supposed that global warming affects the timing of life cycle events in vegetation, also pollen emission phenomenon. According to Ziello et al. (2012) should be necessary to determine the possible contribution of changes in the weather to the increasing trend in allergic diseases. These authors have currently detected a tendency towards an increase in atmospheric pollen of numerous allergenic taxa, above all in northern Europe countries. However, few studies in the warmest Mediterranean areas such as Tunisia have been presented.

Application of appropriate statistical techniques to long-term-phenological data enables fluctuations patterns and overall trends to be analyzed. Although one of the most widely-used techniques has traditionally been linear regression, phenological data do not always fit a linear regression model, and consequently, others approaches should be used. According with a precedent and pioneer study in aerobiological research (García-Mozo et al. 2014), the Seasonal-Trend Decomposition Procedure based on Loess (STL) is a good approach to study phenological trends. The aim of the present study was the use of this procedure for the analysis and interpretation of long-temporal-trends in temperatures amounts and olive reproductive features including full flowering dates and daily pollen concentrations in several Mediterranean areas.

2. Materials and methods

2.1. Study area

In the present study, three Mediterranean areas, located at different latitudes, were selected (Table 1). The Mediterranean climate is characterized by cool, wet winters and hot, dry summers. This climate is also characterized by marked year-on-year variations in the weather pattern, with great spatio-temporal variability (Gasith and Resh 1999). In the study area, the annual mean temperatures are between 14.2 °C (Perugia, Italy) and 21.2 °C (Zarzis, Tunisia). The annual rainfall ranges from 170 mm (Zarzis, Tunisia) to 829 mm (Perugia, Italy).

2.2. Phenological and meteorological data

The study was performed using 19-year database (1993-2011) of pollen and temperature records for each study site. The olive-pollen sampling activities were carried out using the volumetric method, which is based on capturing the pollen and other biological particles present in the air (International Association for Aerobiology 2011). The monitoring traps were inside or near to olive groves, for the detection of the pollen from a wide olive-growing area. This kind of sampling reflects the anthesis phenomenon reducing the subjectivity in the interpretation of the flowering period using field observations (Orlandi et al. 2010). Two phenological features were calculated for each year and study site: (i) the date of maximum daily pollen concentration, i.e., the peak pollen emission date (Julian day) and (ii) the maximum pollen concentration value (grains of pollen/m^3 of air). This information was extracted of the database by mean the calculation of the Effective Pollination Period (EPP), which considers the pollen emission concentrations of the four days preceding the peak pollination date (Orlandi et al. 2005). These phenological variables were chosen because they correspond to the moment when the majority of the olive trees are involved in the full flowering phenomenon, which thus indirectly represents the full flowering periods in the different study sites.

The annual olive yield data (tonnes of olive fruit) were considered as another agronomical variable, and consequently analyzed. This information was provided by the local authorities in each region.

The mean daily temperatures were used to calculate the temperature amounts from 1 March to different pre-established end accumulation dates: 20, 30 April, 10, 20, 30 May and 09 June. These dates were selected to detect patterns in the spring temperature trend linked to biological response.

The daily temperature records were obtained from weather stations nearest to the monitoring units and provided by the Italian National Meteorological and Climatological Centre for Perugia, the Spanish Meteorological Agency for Jaen and the National Institute of Meteorology for Zarzis.

2.3. Long-term trends analysis

Analysis of long-term trends in both the temperature amount and the olive reproductive cycle was performed using two approaches. On the one hand, a Seasonal-Trend Decomposition procedure based on Loess (STL) technique was performed (Cleveland et al. 1990). STL is a filtering procedure for decomposing a seasonal time series into three components: trend, seasonal, and remainder. The trend component is the frequency variation in the data together with non-stationary, long-term changes in level. The seasonal component is considered as the variation in the data at or near the seasonal frequency. The remainder component is the remaining variation in the data beyond that in the seasonal and trend components. In the present study, STL was used to distinguish these components in the time-series data studied.

To assess the trend component that results from the STL decomposing procedure it is helpful to make a trend-diagnostic plot, which eliminates distortions in the interpretation of results. In the elaboration of the trend-diagnostic plots, the trend and remainder data were considered (Cleveland et al. 1990). STL was applied to both the temperature amounts and the variables related to the flowering period, because it is necessary the existence of a yearly periodicity in the data series. Given that the olive fruit production is only an annual data, STL was not applied.

On the second hand, once the different components of the dataset were filtered by the STL decomposing procedure, the trend components were analyzed using the Mann-Kendall test, a non-parametric test for detecting the presence of monotonic increasing or decreasing trends. In this second approach, the use of only the trend component is useful to study the real rising trend over time avoiding distortion due to seasonality or irregularity in the data. In particular, the trend presence was evaluated by the Z coefficient estimation for every variable considered. Positive Z-value manifests the presence of an increase trend inside the data series, while negative Z-value manifests the contrary trend. To estimate the true slope of an existing trend, the Sen's non-parametric method was used (Sirois, 1998). For the four tested significance levels, the following symbols are used in the template: *** if trend at $p = 0.001$ level of significance; ** if trend at $p = 0.01$ level of significance; * if trend at $p = 0.05$ level of significance; and + if trend at $p = 0.1$ level of significance.

The statistical software R version 3.0.2 was used for STL, and Excel template MAKESENS Version 1.0 (Microsoft Inc., Redmond, WA) was used for Mann-Kendall trend analysis.

3. Results

The results derived from STL procedure are presented in Figures 1, 2 and 3, for Perugia, Jaen and Zarzis respectively. The data graphed in the top of the panel (A) are those referred to the temperature amounts, while the central chart (B) presents the full flowering dates. The bottom panel graphs the pollen concentrations during the EPP. In every chart, both the trend and the remainder components extracted by STL and the linear regression trend are shown. To evidence significant trends, the graphic interpretation of STL results was integrated with Mann-Kendall test.

The daily mean temperature amounts during the spring season in Perugia evidenced a clear increasing trend (Figure 1A). The lowest value was recorded in 1995, with an increasing tendency in successive years toward to reach the maximum values recorded in the last years (2007, 2009, 2011) (Table 2). The analysis of Mann-Kendall test confirmed this behavior with a Z value of 3.19 and significance of $p < 0.01$ (Table 3). The chart of the Figure 3B showed the presence of a decreasing trend at least to 2003, while the last values from 2007 were not so accorded to the principal trend. Pollen emission trend (Figure 1C) suggests the presence of a double behavior inside the historical series, with a first higher emission period (1993-1999) followed by a lower second one (2000-2011). Mann-Kendall test confirmed the first impressions derived from the interpretation of the plotted data, showing a large and significant negative Z value of -3.45 and significance of $p < 0.001$ during the entire period but a first positive trend ($Z = 2.03$, $p < 0.01$) during the first 7 years of the temporal-trend.

The daily mean temperature amounts recorded in Jaen study site evidenced a great variability year by year, with values that ranged from 1,014 to 1,263 degree (°C) (Table 2). Both the STL plot and the regression line suggests the absence of a trend with only a weak decrease tendency till the lowest values in 2004 (Figure 2A). The Mann-Kendall test confirmed this behavior, with a non significant Z value of -0.18 (Table 3). The full flowering dates represented in the Figure 2B resulted in accordance with the temperature amount pattern, not graphically showing any clear trend, confirmed also by Mann-Kendall non significant results (Z value = 0.84). The chart of Figure 2C evidenced a particular phenomenon with a first increasing trend till 2003, not confirmed in the successive years of study. In consequence of this first graphic interpretation the Mann-Kendall test was realized in two periods (1993-2003 and 1993-2011). Only the restricted period (first 11 years of the data series) showed a great positive and significant value (Z value = 4.08, $p < 0.001$), confirming the presence of an increasing pollen emission trend till 2003.

Regarding to Zarzis site, the presence of an increasing trend in the temperature amounts was detected (Figure 3A). This trend was quite homogeneous in the first 17 years till 2009, while the last two years presented a particular variability. The temperature amount values were between 1,311 and 1,876 degree (Table 2). The Mann-Kendall test confirmed statistically the precedent interpretation, showing a Z value of 3.08 with a significance of $p < 0.01$. Also flowering dates showed a notable decreasing trend (Figure 3B) confirmed by the Mann-Kendall test results (Z value = -4.20, $p < 0.001$). The pollen concentrations recorded in Zarzis (Figure 3C) show a light decreasing trend considering the entire study period, while the maximum pollen emission value was recorded during 1999 (Table 2). The Mann-Kendall test realized from 1993 to 2011 showed a significant Z value of -1.83, confirming the decreasing trend suggested by the plot analysis.

In Table 3 the Mann-Kendall test values obtained regarding the annual olive fruit production in each study site are also shown. Only in Jaen study site a significant and positive trend was detected, showing a Z value of 3.15 with a significance of $p < 0.01$. It is noteworthy that, in this case, the increasing fruit production trend can be certainly related with the positive pollen emission trend recorded in the same area during the first 11 years of study (1993-2003).

4. Discussion

Many studies have confirmed the strong relationship between climate and life cycle of bio-organisms (Aguilera et al. 2013; Bock et al. 2014; Bonofiglio et al. 2009; Menzel et al. 2006; Orlandi et al. 2014; Osborne et al. 2000; Ziello et al 2012). Warming trends and spatial variability in the rainfall pattern, both expected in the future under different greenhouse emission scenarios, can affect the composition and functioning of natural and managed ecosystems, which could have serious difficulties in adapting to climate change (Alcamo et al. 2007; Food and Agriculture Organisation 2014; Giorgi and Lionello 2008; Moriondo et al. 2013).

A comparison of the temperature amount trends recorded in the three areas evidenced the similarities between Perugia and Zarzis, located in a very close longitudinal range but in the north and south latitudinal limits where olive-producing areas are distributed. In both of them, a significant a clear increasing trend in the spring temperature amount was detected in comparison to the tendency absence recorded in the Spanish area. The similarities between the highest and lowest monitoring stations in terms of latitude were evidenced also by the flowering periods as a probably phenological response to the precedent meteorological trends. Decreasing trends in the full flowering dates of the olive trees located in Perugia and Zarzis sites were evident, but, again, not trend in Jaen was detected. According to Menzel et al. 2006, the temperature response of spring phenology is unquestionable. These authors observed that flowering and fruiting phases are strongly regulated by temperature, in particular at higher latitudes. Peak pollen emission date is being recorded earlier, as has been observed in the Italian and Tunisian study areas, where increasing temperature amounts trends were clearly observed. This result agrees with previous studies that have detected earlier mean flowering dates in numerous plant species within European countries (Bock et al. 2014; Bonofiglio et al. 2009; García-Mozo et al. 2009; 2014; Menzel et al. 2006). The warming tendency observed in the study areas is in accordance to the advance in the timing of the olive flowering period, being therefore reasonably suppose that this phenological stage might manifest particular sensitivity to future global climate change.

Olive pollen emissions are decreasing, phenomenon more evident in the highest and lowest latitudinal study sites. Both olive-growing areas manifested the major pollen emission during 1999 and after that year the concentrations decreased determining the negative trends obtained considering the entire study period. The noticeable increase in the temperature trends recorded in these areas could be the main reason to explain this fact. Higher temperatures during the spring months, when the olive flowering period takes place, may have a double effect. In the warmest Mediterranean areas, excessive temperatures can be a limiting factor for the metabolic activity of the olive tree and negatively influence several reproductive parameters, including flower development, pollen production, pollen-tube growth and also pollen viability (Cuevas et al. 1994; Krueger, 1994). On the other hand, and according to precedent studies, increase in temperature could limit the physiological performance of the plant species that grow in high latitudes at lower temperatures, including pollen release (Emberlin et al. 2002; Ziello et al. 2012). Advance in first flowering would be necessary to ensure the success of the pollination and fertilization processes, being an adaptive phenomenon of the olive tree phenology to higher spring temperatures.

The decrease in the airborne pollen concentrations obtained in the present research could be considered surprising in view of a recent study reporting an increase in the olive pollen emission in southern Spain, area where, otherwise, we have not obtained significant trends considering the study period as a all (García-Mozo et al. 2014). The increase in the pollen levels detected for these authors can be partially attributed at the increase of land surface devoted to olive cultivation suffered by this area in the last years. Indeed, this can be considered the main cause of the clear and positive trend detected in the olive fruit production of Jaen, where a yearly increase in the cultivation area till 2003 is documented (Aguilera et al. 2012b). Moreover, Ziello et al. (2012) observed a tendency towards an increase in atmospheric pollen in several Northern Europe countries, although decreasing trends were found for Spain. Inconsistent results regarding to the airborne pollen trends not allow give a conclusion, and, therefore, further research should be needed.

The use of the Seasonal-Trend Decomposition Procedure based on Loess has result a good approach to study long-term meteorological and phenological trends. According to García-Mozo et al. (2014), removing both the seasonal and the remainder components, avoiding therefore the random features linked to the seasonal variability of the Mediterranean climate, the real rising trends over time can be interpreted. This statistical technique is particularly useful to study natural processes with a clear seasonal component, such as olive pollen season.

Considering the findings presented in this study, the temperature increase may reduce the atmospheric pollen levels and, consequently, the human exposure to olive pollen in the Mediterranean area. Moreover, public health, in terms of pollen allergy, would be also benefit by a shortening of the pollen emission period, such has been suggested by Bock et al. (2014). Nevertheless, since an agronomical point of view, flowering advance and/or lower pollen emission could have negative effect on the pollination phenomenon, leading to decline in agricultural crop production.

Conclusions

The findings herein imply that increasing temperatures result in both olive tree flowering advance and lower airborne pollen emission. The pattern is clearer in the highest and lowest latitudes where the olive cultivation is present, but not in the intermediate latitudes such as the Spanish area, where more research should be needed.

Seasonal-Trend Decomposition analysis by Loess is a good approach to study long-term phenological trends in Mediterranean species with seasonal component such as the olive tree.

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References

Table 1. Main features of the study sites. T, mean annual temperature; Pp, total annual precipitation

Study site	Country	Coordinates	Altitude (m a.s.l)	T (ºC)	Pp (mm)
Perugia	Italy	43°06'N, 12°23'E	450	14.2	829
Jaen	Spain	37°48'N, 03°48'W	568	17.1	485
Zarzis	Tunisia	33°35'N, 11°01'E	17	21.2	170

Table 2. Summary of the main features of the STL-trends: Temperature amounts (ºC), Flowering dates (Julian day), Pollen concentrations (grains of pollen/m^3)

	Min	Max	Mean	SD
Temperature amount				
Perugia	746 (1995)	1,087 (2007)	911	83
Jaen	1,014 (2004)	1,263 (1997)	1,129	51
Zarzis	1,311 (1995)	1,876 (2010)	1,432	113
Flowering date				
Perugia	145 (2007)	168 (1995)	155	5
Jaen	121 (1997)	154 (1993)	133	4
Zarzis	97 (2010)	133 (1993)	114	8
Pollen concentration				
Perugia	89 (2011)	1,093 (1999)	366	233
Jaen	1,327 (2005)	8,462 (2003)	3,347	1,360
Zarzis	4 (2001)	2,703 (1999)	694	542

Min, minimum value; Max, maximum value; SD, standard deviation

Table 3. Mann-Kendall trend for Temperature amounts (ºC), Flowering dates (Julian day), Pollen concentrations (grains of pollen/m^3) and Olive fruit production (tonnes)

Time series	First year	Last year	n	Test Z	Signific.	Sen's slope estimate (Q)
Temperature amount						
Perugia 1mar-30may	1993	2011	19	3.19	**	13.71
Jaen 1mar-10may	1993	2011	19	-0.18		-1.20
Zarzis 1mar-20apr	1993	2011	19	3.08	**	8.06
Flowering date						
Perugia	1993	2011	19	-1.58		-0.05
*Perugia **	*1993*	*2003*	*11*	*-4.77*	***	*-0.25*
Jaen	1993	2011	19	0.84		0.05
Zarzis	1993	2011	19	-4.20	***	-0.20
Pollen concentration						
Perugia	1993	2011	19	-3.45	***	-3.81
Jaen	1993	2011	19	1.06		10.30
Zarzis	1993	2011	19	-1.83	+	-3.78
Olive fruit production						
Perugia	1993	2011	19	1.26		718.83
Jaen	1993	2011	19	3.15	**	101494.50
Zarzis	1993	2011	19	-0.81		-1187.50

*** if trend at p = 0.001 level of significance; ** if trend at p = 0.01 level of significance; * if trend at p = 0.05 level of significance; + if trend at p = 0.1 level of significance. mar, march; apr, april

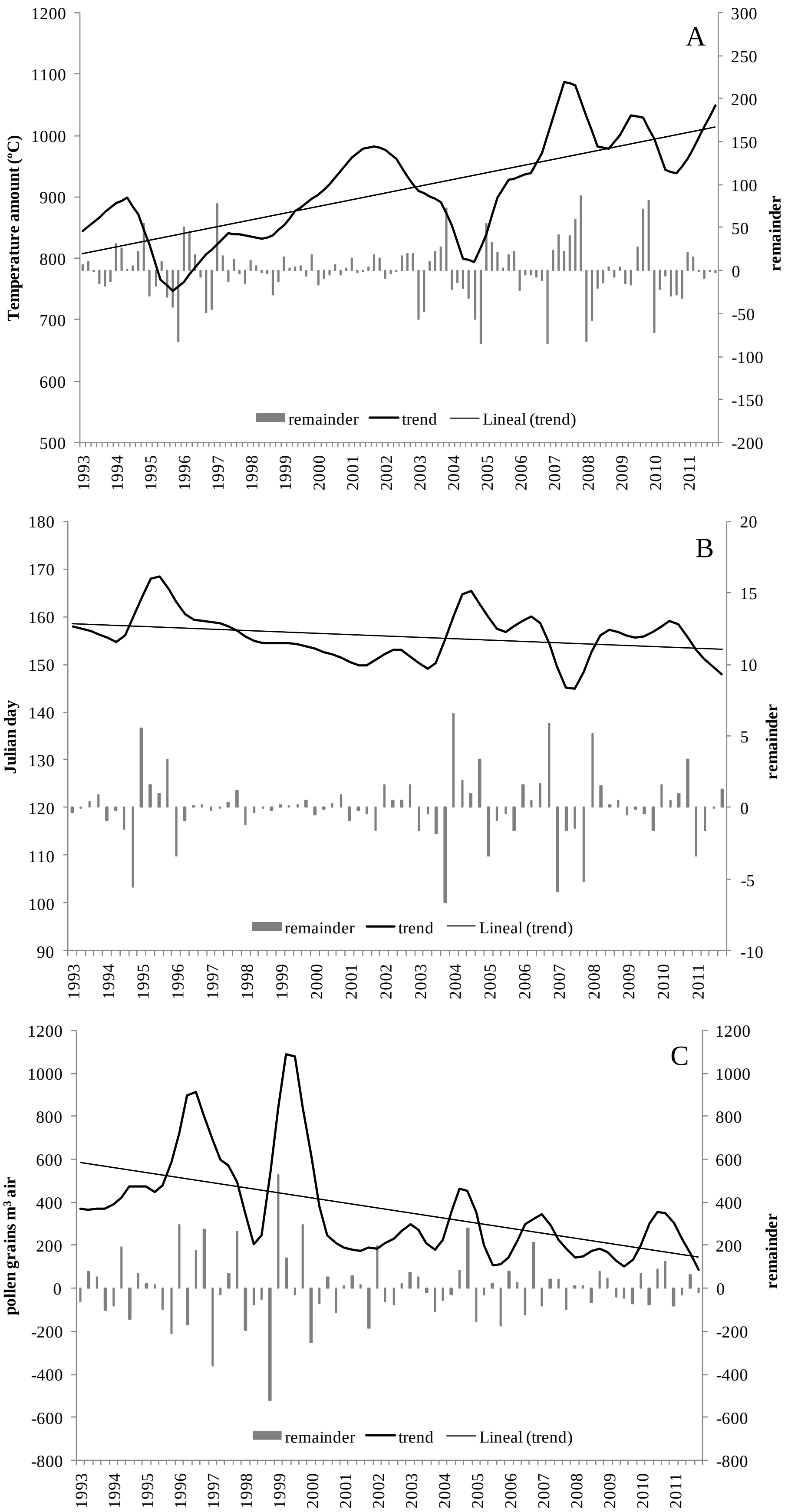

Figure 1. Trend-diagnostic plot for Temperature amounts (A), Flowering dates (B) and pollen concentrations (C) in Perugia study site

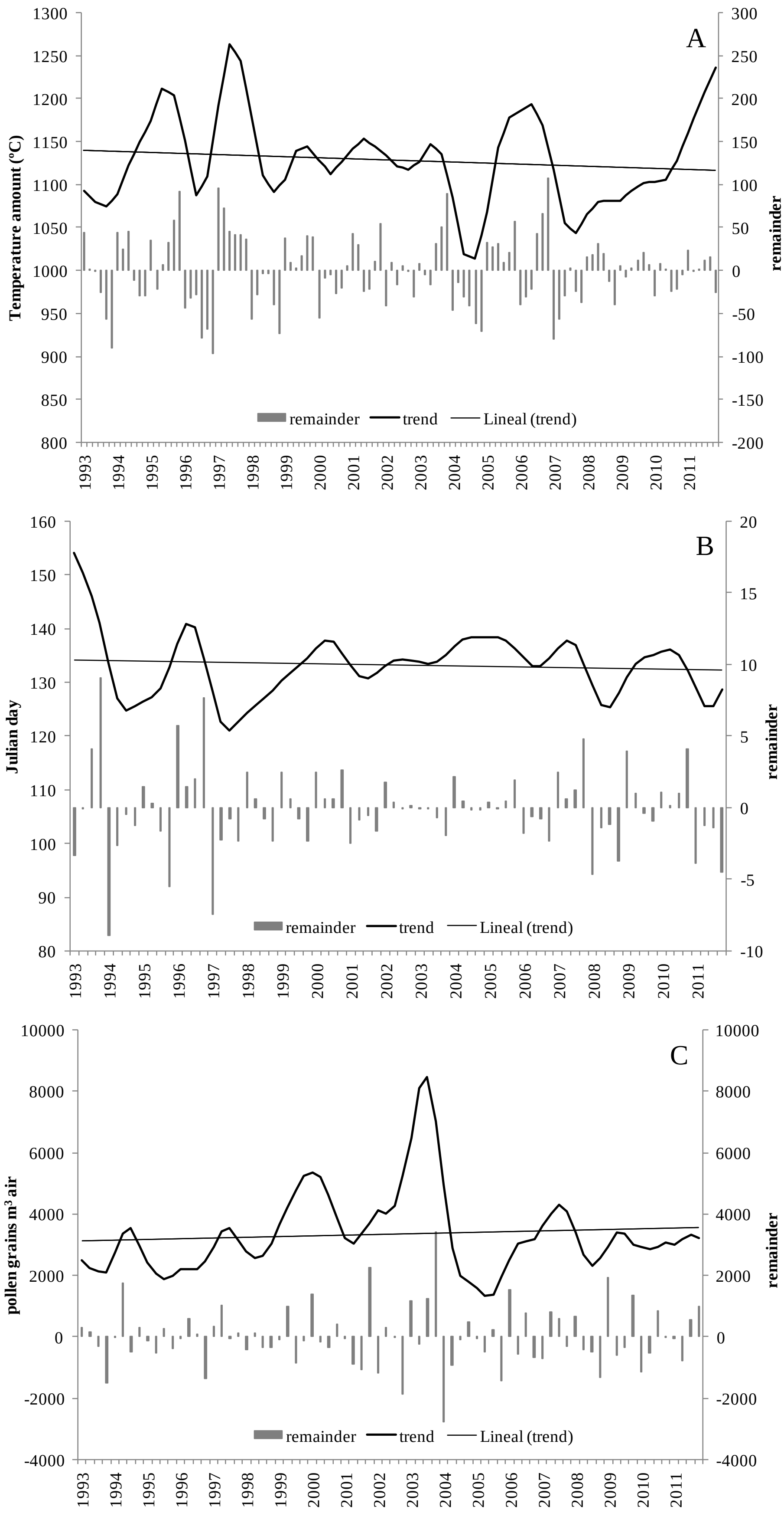

Figure 2. Trend-diagnostic plot for Temperature amounts (A), Flowering dates (B) and pollen concentrations (C) in Jaen study site

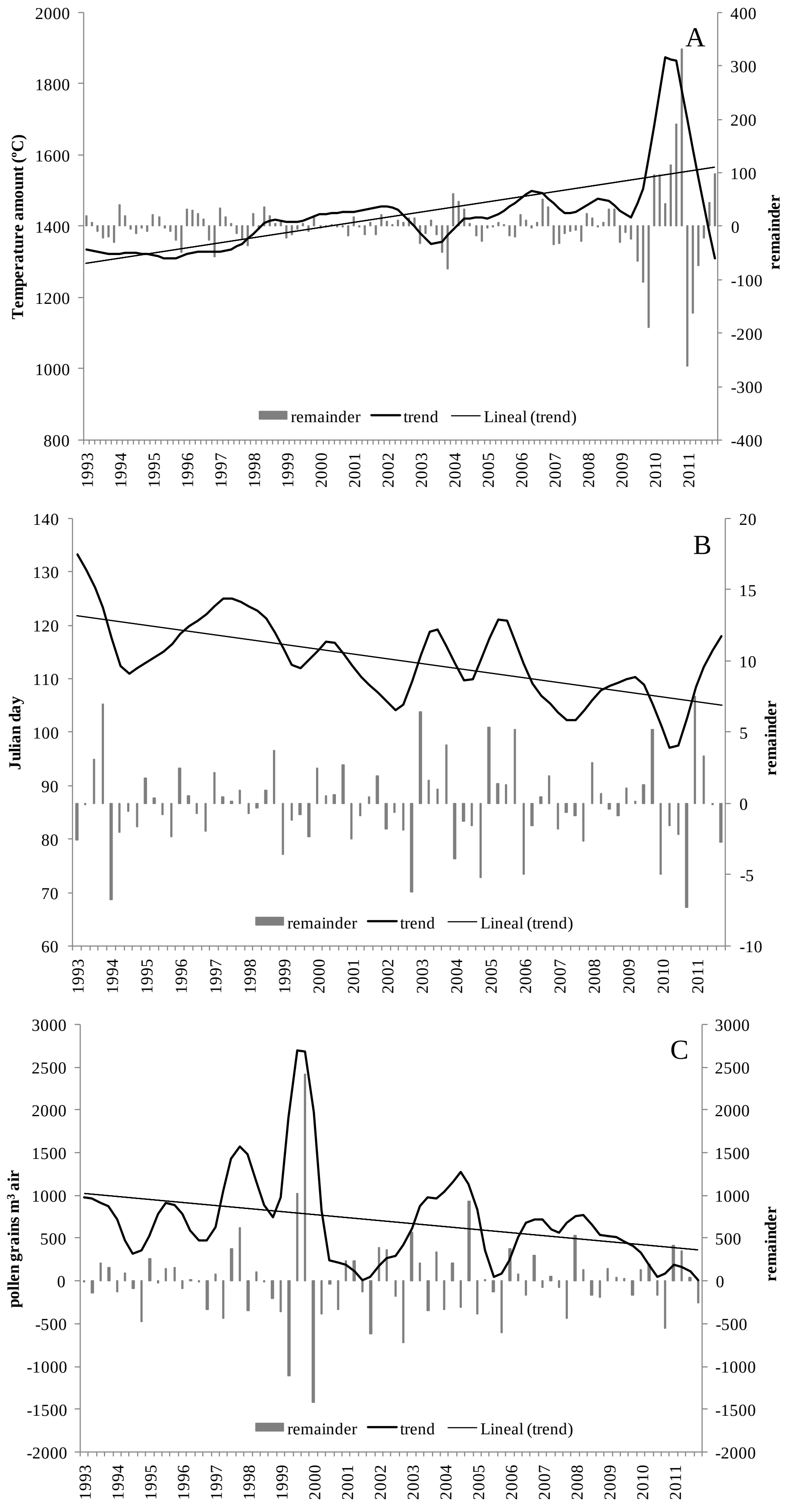

Figure 3. Trend-diagnostic plot for Temperature amounts (A), Flowering dates (B) and pollen concentrations (C) in Zarzis study site